ECE 443: Senior Capstone
Project Closeout

Group 01 (ECE):
Using Ocean-going Robots to Observe Wave Conditions

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Design Impact Assessment

2.0 Public Health, Safety, and Welfare Impacts

The Wave Condition Monitoring system has strong ties with public health, safety, and welfare. Ocean waves and ocean surface condition measurements are traditionally difficult metrics to sense and record, due to the accessibility of the off-shore ocean. Things such as wave forecasts for recreational ocean-goers, like surfers, are incredibly difficult to gather data from accurately in order to portray if conditions are safe enough to surf in. This same concept applies - perhaps to a larger degree - to ships and ocean-vessels travelling off-shore. Radio feeds are reliable only for anecdotal evidence (another human being reporting what they see), whereas our project would report exact metrics; measured data that can not only help people make safe decisions regarding wave conditions, but can help equipment do it for them as well [1]. With our Wave Condition Monitoring system being entirely remote, these measurements take place off-shore and require no maintenance, as the system is housed in a completely unmanned drone which can last for months at a time, thanks to our extraordinarily low power profile.

3.0 Cultural and Social Impacts

Although loose, the Wave Condition Monitoring system could have a positive impact on cultural and social aspects to communities, especially scientific communities, communities associated with living by the ocean, or even young audiences who might be interested in STEAM (Science, Technology, Engineering, Art, and Math). Most especially, sources show that typically large, complex, or otherwise striking or impressive *robotic* systems or exciting and interactive *projects* have a great impact on younger audiences, and can get them interested in STEAM curriculum. [2] This system could have a great effect on the teaching and learning of young children, especially with some of the concepts involved in it's operation, such as what waves are, how ocean tides work, etc.

This system could also help the scientific community by getting the attention of lay-men audiences and showing how systems like this can help everyday people, especially people who interface with the ocean often. With such a large stigma in the United States surrounding the divide between science and application , it could help to bring communities together to show how science can influence application.

4.0 Environmental Impacts

The environmental impacts of this system are immense. In particular, soil science is a large area that interacts with surface wave conditions of the ocean, and having automated, remote sensing of these conditions with exact measurements would greatly improve the speed and accuracy of certain fields within soil science and erosion control in regards to beaches and ocean shores. This could also have an impact on studies involving ocean-shore marine life and monitoring of such ecosystems. [3]

5.0 Economic Factors

The economic factors of this project can be seen from very close up. Traditional remote sensing applications for wave conditions involve using large, expensive floating buoys to sense wave motion. [4] Our system is small, much less expensive, and deployable. This means that not only does the entire system cost less, but the system can sense wave conditions anywhere within a reasonable radius of its deployment, whereas moving these wave monitoring buoys is extraordinarily difficult, expensive, and impractical. Having such a low power system onboard this AUV also means that other systems can exist onboard, sensing all sorts of invaluable information about the ocean with the same drone, collecting data for a multitude of disciplines, for weeks or even months at a time.

Project Timeline

Meetings were held with the entire team (ECE and CS team, as well as our project partners) every Friday.

Ocean-Going Robots: ECE

GANTT CHART

TASK NAME	DURATION (Weeks)	TEAM MEMBER	Fall Term					Winter Term											Spring Term									
			7	8	9	10	F	11	12	13	14	15	16	17	18	19	20	F	21	22	23	24	25	26	27	28	29	30
Researching and Planning																												
Find suitable MEMS sensor and Microcontroller	2	Derek																										
Teamwork Reflection Paper	2	All																										
Final Engineering Requirements	2	All																										
Final Block Diagram	2	All																										
Block Validations	4	All																										
Block Checkoff (Individual) Phase																												
SDCard	6	Nick																										
Power	6	Austin																										
Sensor	6	Derek																										
Compression	5	Nick																										
LEDs	3	Nick																										
Firmware	7	Austin																										
Controller	8	Derek																										
Processing	7	Derek																										
Enclosure	5	Austin																										
First Block Checkofff	1	All																										
Second Block Checkoff	1	All																										
Final Block Checkoff	1	All																										
Designing and Revising (Group) Phase																												
Bill of Materials	4	Austin																										
Schematic	4	Derek																										
PCB Layout	3	Nick																										
Send PCB for Fabrication	1	Austin																										
Purchase Bill of Materials	1	Austin																										
Final Assembly and Testing																												
Toy Glider Design and construction	5	Austin																										
PCB Assembly	3	Nick																										
Bench top PCB Testing	3	Nick																										
Interface with CS Team Software	3	Nick																										
Toy Glider in Buoyancy Tank	2	Derek																										
Real Glider in Buoyancy Tank	2	Austin																										
Toy Glider in Wave Lab	2	Derek																										
Real Glider in Wave Lab	2	Austin																										
Toy Glider in small wave marine environment	2	Derek																										
Real Glider in small wave marine environment	2	Austin																										
Toy Glider in near shore ocean environment	2	Derek																										
Real Glider in near shore ocean environment	2	Austin																										
Toy Glider in an ocean environment near a buoy with calibrated wave spectra	2	Derek																										
Real Glider in an ocean environment near a buoy with calibrated wave spectra	2	Austin																										
Miscellaneous																												
Poster Draft	2	All 3																										
Project Closeout Packet	2	All 3																										
Project Video	3	All 3																										
Final Poster	2	All 3																										
System Review 1	1	All 3																										
Final System Review	1	All 3																										
Virtual Expo	3	All 3																										
Class BBQ that's totally happening with COVID	1	All 3																										YAY

Scope and Engineering Requirements Summary

Summary

The system must fit inside the center subsection of the glider, mounted and connecting to one of the available headers on the science computer. This system must be tolerant of cold temperature and pressure, down to -10 C and 1 ATM. Project partners or glider users must be able to remove the system from the glider with ease, and upload saved data onto an external computer for processing. The system must be able to send and receive serial data to and from the science computer during operation, and process and transmit significant wave height spectra while operating on the surface. The system must also compress and store all data sampled from the MEMS sensor onto a high capacity SD card. Lastly, the system must be low power to maintain a substantial deployment time, < 40mW.

1. **Board Size**

PR: Product must be able fit inside an existing glider.
ER: The system will be no larger than 50mm * 50mm * 50mm.
Verification Method: Test
Testing Process:

1. Measure the system.
2. Confirm that the system does not exceed specified size.

Testing Pass Condition: When measured, the system does not exceed a 50mm * 50mm * 50mm box.

2. **Cold Temperature Resistance**

PR: System is resistant to cold temperature.
ER: System will take orientation measurements with < 15% error when submerged in water < 20 degree Celsius.
Verification Method: Analysis
Testing Process:

1. Set up a wrapper test bench to output quaternion (orientation + heading) values. (This is done because it is the best way to test and view the data.)
2. Place our system in a waterproof bag and submerge the bag in tub of cold water (measured < 20 deg Celsius)
3. Wait for 1 minute for the system to be cooled, then power on the system, and send the start command.
4. Look at orientation values.
5. Rotate the system 180 degrees in the water tub.
6. Compare the new orientation values, use quaternion multiplication to ensure ends values are within 15% error.

Testing Pass Condition: The visual output should see resulting orientation data within 15% error of result from analysis. (Given input)

3. Ease of Access

PR: System must be easy to install/remove from the glider.
ER: The project partner must remove and install the system in a glider in under 15 minutes, nine out of ten times.
Verification Method: Test
Testing Process:

1. The project partner is timed with installing and removing the system from the internal science bay of the underwater glider.
2. Repeat for a total of 10 trials

Testing Pass Condition: The project partner is able to successfully install/uninstall the system into a glider in under 15 minutes, nine out of ten trials.

4. Low Power

PR: The system must consume little power for long missions.
ER: The system will not exceed an average power consumption of 40mW, over a 1 hour period.
Verification Method: Test
Testing Process:

1. Connect DMM or power supply with current reading in series with the power supply to the system under test.
2. Track the current consumption of the system over the course of 20 minutes (the average time for each surface measurement session of the glider).
3. Calculate the maximum energy consumed by the system over this 20 minute period.
4. Compare the maximum energy consumption value of the system with the energy consumption of 40mW over one hour (0.04 W * 3600 s = 144 J).

Testing Pass Condition: The maximum calculated energy consumption of the system is less than or equal to 144J. This proves that the system will not exceed an average power consumption of 40mW over a 1 hour period.

5. Margin of Error

PR: Margin of error for measured wave data should be reasonable.
ER: The system stored sensor data for acceleration, orientation, and heading will have less than 10% error.
Verification Method: Analysis
Testing Process:

1. Set up wrapper test bench to output quaternion (orientation + heading) and acceleration values. (This is done because it is the best way to test and view the data.)
2. Power on system, send start command.
3. Look at orientation values.
4. Rotate the system 180 degrees.
5. Compare the new orientation values, use quaternion multiplication to ensure ends values are within 10% error.
6. Drop the device.
7. Ensure resulting Z acceleration values reach -9.8 within 10% error.

Testing Pass Condition: The visual output should see resulting acceleration data and orientation data within 10% error of result from analysis. (Given input)

6. Onboard Storage

PR: System must include on board storage for further analysis on land.
ER: System must store at least 20 GB of high frequency motion data.
Verification Method: Inspection
Testing Process:

1. Start with a micro SD card with 21 GB worth of dummy data already stored on it, and insert it into our board.
2. Let the system store additional data to the micro SD card.
3. Remove the micro SD card from the system. It should contain both the unchanged initial 21 GB, as well as the new data.
4. Read the micro SD card at a computer to confirm that the system was able to store the 21 GB of dummy data after adding new data.

Testing Pass Condition: Confirm that the micro SD card contains both the initial 21 GB of dummy data and the additional collected data, which shows that the system is capable of storing at least 20 GB and does not overwrite existing data.

7. Record Wave Data

PR: Be able to accurately record wave data.
ER: The system will produce an estimated significant wave height (SWH) measurement within an error of +/-30%
Verification Method: Test
Testing Process:

1. Using a physical test apparatus, give the sensor a sinusoidal wave input.
2. Compare the system's SWH reading output to the amplitude of the wave input.

Testing Pass Condition: If the system produces a SWH reading of +/-30% to the amplitude of the input, the system passes.

8. Serial Communication

PR: System communicates with existing hardware using a serial interface.
ER: System must communicate with an existing on board science computer using a serial interface and relay measured data.
Verification Method: Demonstration
Testing Process:

To test our system's serial communication in lieu of the science computer aboard the underwater glider, we will be using RealTerm, a serial capture program, at 9600 baud.

1. Confirm that the baud is set to 9600.
2. Using RealTerm, we will send the message "set time 1613957247.639556" (it will appear in green) over the serial connection. (This is an example UTC time value).
3. Using RealTerm, we will observe the system immediately respond with "TIME SET:" (which will appear in yellow), proving that it can receive commands over serial.
4. To show that it is relaying measured data, we will wait until it outputs the calculated significant wave height (SWH) at the end of data collection.

Testing Pass Condition: If measured data is transmitted to RealTerm over serial in response to a received command, this proves that the system can both receive and transmit information.

Risk Register

We learned that the worst risks are the ones you are unable to foresee. For instance, we did not anticipate parts of our code being incompatible with each other, despite being totally unrelated. We also did not anticipate that our initial choice of microcontroller isn't powerful enough to perform the level of digital signal processing our project partners needed, which led to delays in our project timeline.

ID	Risk Desc.	Category	%		Performance indicator	Responsible party	Action Plan
R 1	Conditions are stormy on day of testing	External / Timeline / Environ-mental	75%	M	Local weather reports for the area where we will have our tests indicate stormy weather.	Derek, Austin and I will check weather reports in the weeks before we are scheduled to do our live tests on the ocean.	Retain: Reschedule for the next clear day. Alternatively ask project partners if it is okay to proceed despite weather if it's not too bad.
R 2	Sensors don't come calibrated correctly.	Internal / Technical	30%	H	Sensor data has unexplained changes or experiences a large degree of drift over time.	Any team member who visually inspects our sensor data	Retain: There isn't anything we can do about poorly calibrated sensors except write code to handle it after the problem is identified. Contacting the manufacturer is a possibility as well.
R 3	Serial Interfaces do not communicate properly	Internal / Technical	15%	M	If the serial definitions provided by project partners aren't specific or if there isn't clear communication for whoever writes our side of the serial code.	Either the science computer or our system could be the source of the problem. Project partner if science computer is wrong, ECE team if our system is wrong.	Retain: Debug using a serial interface that is known to work and test each side independently. Review serial interface standards and definitions. Use oscilloscope to aide in debugging if methods above don't clear the issue.
R 4	Break microcontroller	Internal / Cost / Timeline	25%	H	If we don't use ESD equipment or don't read the datasheet	Whoever is assigned to solder the microcontroller	Reduce by following best practices. If this happens anyway, confirm that the board

					thoroughly before writing firmware.	and everyone on both teams for firmware. (CS+ECE)	is indeed broken beyond repair, then buy a new microcontroller and review best practices.
R 5	PCB traces too thin	Internal / Technical	10%	H	If we don't calculate the maximum and average current though each of the power traces, this will be easy to forget about.	I will compare trace thicknesses with a copper thickness amperage chart.	Reduce by making current calculations. If this risk happens, we will have to immediately redesign and ship the board if we are low on time.
R 6	Wave Lab Closed due to COVID	External / Timeline / Facilities	50%	M	Other labs connected with the college are closing due to COVID.	Derek will check lab availability weeks prior to our first wave lab testing.	Retain/Transfer: See if lab visit can be rescheduled with fewer people and stricter social distancing. Project partners may have more influence that can help gain access to the lab.
R 7	Exceed allocated funding	Internal / Project Mngmt. / Cost	15%	H	Team breaks expensive components or must make additional PCB orders.	I will track expenditures and alert the team at regular intervals.	Retain/Transfer: Unless the funding is only slightly too low, we would have to ask our project partners for an extended budget.
R 8	License for launching UAV off coast is lost or expires	Internal / Timeline / Legal	5%	H	If the project partners don't discuss their UAV license with us.	Project partners will have to know if or when their license to launch UAVs expires.	Transfer: Project partners must contact the appropriate agency to renew their license. High risk because of bureaucracy time delays.

Future Recommendations

1. Implement File Transfer
One thing our project partners were interested in was wireless file transfer. The reasoning behind this is that our system stores lots of data, but to actually access the raw data and not just the significant wave heights, the SD card needs to be pulled out and read. Opening the glider to get the SD card takes time and must be done carefully, making it unideal in the field.
Recommendation
Implement the ability to transfer data from the SD card to the science computer, and then tell the science computer to transfer it over wireless (eg ZMODEM) to a base station. There shouldn't be any additional hardware required for this, you would just have to start by talking with Pat about designing a command for the science computer to initialize wireless transfer.

2. Convert System to an RTOS
Having a single main file caused lots of problems for us, and I think an RTOS might help alleviate these problems. There were major incompatibility issues as well as timing issues, which are what an RTOS is designed to fix.
Recommendation
As a starting point, the STM32L4R5 we're using can definitely be used as an RTOS using FreeRTOS. There are also RTOS settings in STM32CubeIDE, the IDE we used for the entire project. The challenge would be turning the existing code into RTOS tasks.

3. Implement Error Detection for Data Storage
Pat had recommendations for more robust data storage that involved error detection on the data, as well as other redundancy features such as including the starting time stamp in the file itself and not just the file name.
Recommendation
Talk to Pat and see if he can find the email he sent to Nick regarding CRC, file signatures, and byte order marks (Apr 21, 2021). This is a detailed account of what he was looking for in the final system, but unfortunately we did not have time to implement it.

4. Revise the PCB
The current PCB works great, however to get to this state we had to short some pads together. We can also shrink down the PCB some more, as there is still dead space on the board. This will help our system take up even less room inside the gliders, and make installation easier, since it will be in the way of less stuff.
Recommendation
90 degree connectors would help decrease total system size, as well as generally shrinking the board size. 0201 LEDs were a nice way to show off Derek's soldering skills, but a more reasonable size would be appreciated by future teams trying to assemble the board. In addition a second or even third revision could allow for further optimization of components, and perhaps use of a BGA package for the microcontroller to shrink size down further.

5. Better Noise Reduction

Currently the significant wave height estimate has minimal filtering when processing the measured acceleration values, and it does not implement any sort of tilt correction. This both has a large impact on the non-directional estimate and means that the software application would have to do this correction instead.

Recommendation

Add multiple filters (e.g. Kalman filter or rolling average) to smooth and reduce noise on data before performing frequency spectrum analysis.

6. Better Power Reduction

Currently the power use is fairly low, however it could be reduced even further. Several power saving methods were not implemented due to other constraints.

Recommendation

Implement a dynamic clock speed, and turn off other power domains on the microcontroller when not in use. LPUART1, the UART we're using, can be woken up from some sleep modes by interrupts to allow for further power saving when awaiting a serial command.

7. Update the Mounting Hardware

The system currency utilizes a 3D printed clip on enclosure. While it has performed well in testing, there are longer lasting and more rigid ways to mount the system in the glider.

Recommendation

Tap some standoffs on the bulkhead plate near the wire connectors. The current brackets used for affixing the system have 3 x M3 mounting holes. I might also recommend using a material that is more resilient than PLA. i.e. CNC Aluminum

8. More Elegant Processing Path

The current system attempts to solve the main dilemma of high performance with low power draw by utilizing an STM32L4 microcontroller, which has support for DSP instructions and high amounts of memory while still consuming a small amount of current, however further optimizations could be made if signal processing was implemented with hardware instead of software.

Recommendation

Use dedicated DSP IC's to process the various inertial signals from the sensor. This could allow for much faster and less power intensive calculation of wave spectra on the glider, possibly even allowing for all directional and non-directional spectra to be estimated.

References

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